

## **REMARKS**

This Preliminary Amendment cancels, without prejudice, claims 1 to 20 in the underlying PCT Application No. PCT/EP02/13702 and adds new claims 21 to 40. The new claims, inter alia, conform the claims to United States Patent and Trademark Office rules and does not add any new matter to the application.

In accordance with 37 C.F.R. § 1.125(b), the Substitute Specification (including the Abstract) contains no new matter. The amendments reflected in the Substitute Specification (including Abstract) are to conform the Specification and Abstract to United States Patent and Trademark Office rules or to correct informalities. As required by 37 C.F.R. §§ 1.121(b)(3)(ii) and 1.125(c), a Marked-Up Version of the Substitute Specification comparing the Specification of record and the Substitute Specification also accompanies this Preliminary Amendment. Approval and entry of the Substitute Specification (including Abstract) are respectfully requested.

The underlying PCT Application No. PCT/EP02/13702 includes an International Search Report, dated October 23, 2003, a copy of which is included. The Search Report includes a list of documents that were considered by the Examiner in the underlying PCT application.

The underlying PCT Application No. PCT/EP02/13702 also includes an International Preliminary Examination Report, dated May 18, 2004. An English translation of the International Preliminary Examination Report and annex thereto are included herewith.

It is respectfully submitted that the subject matter of the present application is new, non-obvious and useful. Prompt consideration and allowance of the application are respectfully requested.

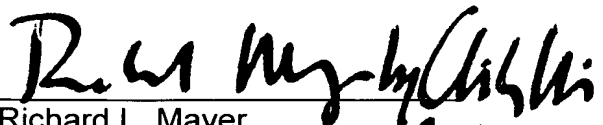
Respectfully submitted,

KENYON & KENYON

Dated:

July 12, 2004

By:

  
Richard L. Mayer  
Reg. No. 22,490  
One Broadway  
New York, New York 10004  
(212) 425-7200  
CUSTOMER NO. 26646  
*13,110. 42,194*

METHOD FOR INTERPOLATING AT LEAST TWO  
POSITION-DEPENDENT, PERIODIC ANALOG SIGNALS THAT  
ARE PHASE-SHIFTED WITH RESPECT TO ONE ANOTHER

Detailed Description

**FIELD OF THE INVENTION**

The present invention relates to a method for interpolating at least two position-dependent, periodic analog signals that are phase-shifted with respect to one another, ~~according to the definition of the species in Claim 1.~~

**BACKGROUND INFORMATION**

Such a method is used to interpolate analog signals generated by scanning a measuring graduation, for position-measuring, i.e., especially for measurement of lengths and/or angles. In this connection, the analog signals are respectively converted into a digital data stream, with the aid of a sigma-delta modulator, ~~for.~~ **For** generating a (single) string of results, the at least two data streams are then first combined with correctional factors and subsequently with one another, ~~and from.~~ **From** the string of results, on the one hand, new correctional values are generated in the light of the quality criterion to be satisfied (by the values of the string of results), and on the other hand, the output signals of the interpolation are generated.

The at least two analog signals are particularly phase-shifted by 90° to one another, and are essentially sinusoidal, the latter also including analog signals generated from the sine function by phase-shifting, such as cosine signals.

Such a method is ~~known from DE~~ **described in German Published Patent Application No. 199 38 802 A1.** In this method, the string of results is supplied to a digital filter, which

restores certain data of the input signals, and which subsequently increments or decrements a phase counter as a function of the output value of the filter. The phase value generated hereby is used on the one hand (up to the fulfillment of the quality criterion) for determining new correctional values, and on the other hand for determining the output signal of the interpolation. For the satisfaction of the quality criterion, the string of results generates a signal sequence or string in a filter, at simultaneous decimation, which, after comparison to the quality criterion, controls the correctional values in such a way that the string of results approaches this quality criterion, and in addition, a string of addresses is formed from which, after low-pass filtering and association, the output signals are generated.

~~From DE~~ German Published Patent Application No. 195 02 276 At describes an interpolation method ~~is known~~ for interpolating at least two sine-like analog signals, for measuring paths and/or angles, that are obtained by the scanning of a graduation carrier, are position-dependent, periodic and phase-shifted by  $90^\circ$  to one another, in which noise is superimposed on the analog signals in each case using sigma-delta modulation, in which, from the thus generated data strings, upon simultaneous first incomplete low-pass filtering of the noise components above the maximum input frequency of the analog signals, sequences of signals are generated, and in which, from the sequences of signals, a sequence of angular values is obtained to which is assigned, after a second low-pass filtering of the still-present noise component, above the maximum input frequency of the analog signals, a string of output values.

~~From DE~~ German Published Patent Application No. 195 06 276 At describes a method ~~is known~~ for interpolating sensor signals, in which respectively one sine signal and one cosine signal of a sensor is supplied to a bridge circuit having several

tapping points and a value comparison is carried out between a tapping pair, made up of two tapping points which ~~lie~~ are diametrically opposite in the bridge circuit. If a value equality between the tapping pair is determined which  
5 corresponds to a zero crossing of the scanning value, a signal representing the setting of the corresponding tapping pair is emitted. In this context, the tapping pairs are scanned one after another in one direction, are subjected, one after another, to the value comparison, and a count value is  
10 assigned to each scanning event. Appropriate to the result of the comparison, a phase counter is incremented or decremented.

~~The present invention is based on the object of further improving an interpolation method of the type named at the outset.~~  
15

#### SUMMARY

~~This objective is achieved in accordance with the present invention by devising a method having the features of Claim 1.~~  
20

According to that an example embodiment of the present invention, the values of the string of results for generating the correctional values as well as the output signals are accumulated over a specifiable time interval, and the signal  
25 sequence generated by the accumulation is used directly as address sequence for generating the correctional values and the output signals.

Thus, according to an example embodiment of the present  
30 invention, to form an address sequence, a phase counter is not simply incremented or decremented, but rather, by accumulation, a phase value having a fractional proportion is generated. Thereby ~~is~~ may be achieved a more exact phase correction, a lower gain of the loop used to satisfy the  
35 quality criterion, and consequently improved dynamics of the overall system. In the accumulation over a specified time

interval (decimation of the data stream) the time interval is may be selected in such a way that, from the accumulated values of the string of results, the phase of the analog signals may specifically be determined.

The accumulation of the values of the string of results ~~preferably takes~~ may take place in a filter, and, ~~to be sure,~~ particularly e.g., in a filter in the form of an integrator.

The address values of the address sequence formed by the accumulation represent in each case the phase information of the input-side analog signals, and are linearly dependent on the phase of at least one periodic analog signal, when the quality criterion is satisfied. That means, that if the generation of the output signals has advanced so far that the string of results or the address sequence generated therefrom approach a predefined quality criterion, there is then a linear association between the address values and the phase of the input-side analog signals.

~~Finally, from~~ From the address sequence, the output signals of the interpolation are able to be generated by low-pass filtering and subsequent assignment of the address values.

According to an example embodiment of the present invention, the address values of the address sequence represent a phase value having a fractional component, for the generation of the correctional value the high-value part of the address sequence being used, which corresponds to an incremental component of the address sequence, and, for the generation of the output signals of the interpolation, the high-value and the low-value part of the address sequence being used. The latter corresponds to the fractional part or proportion of the address sequence.

The higher-value part of the address sequence is defined in such a way that the address depth of the correctional values assures the desired interpolation. If, for example, the period of a sine type of input-side signal is to be subdivided 32-fold for the desired interpolation, the higher-valued part of the address sequence ~~must~~ should have a width of 5 bits. The remaining, low-valued part of the address sequence determines the fractional component of a phase increment.

All in all, the determination of the output signals of the interpolation takes place recursively, using a closed loop, in that, in the light of the quality criterion, new correctional values are generated and combined with the digital data streams generated from the input-side analog signals, as long as the quality criterion is satisfied.

The possible correctional values, in which particularly values of trigonometric functions (sine functions and/or cosine functions) may be involved, may be stored as predetermined values in an assignment unit. From the values stored in the assignment unit, the correctional values to be combined respectively with the individual data of the digital data streams are selected in the light of the quality criterion, as a function of the current address values of the address sequence. In this context, the quality criterion may optionally be applied directly to the values of the string of results, in that, a corresponding combining unit is preconnected to the filter (integrator) that is used for generating the address sequence, or this combining unit is combined with the filter (integrator) to form one unit.

For the generation of the string of results, the individual data of the digital data streams generated from the input-side analog signals are in each case combined multiplicatively with a correctional factor, and subsequently the data of different

data streams are combined with one another by addition or subtraction.

The sigma-delta modulator ~~is preferably~~ may be designed in such ~~a way~~ that the individual data of the digital data streams, generated thereby, in each case have a word width of only one bit.

In the case of an exact phase position and a sinusoidal pattern of the input-side analog signals, the values  $d$  of the string of results are formed according to the formula  $d = s_1 \cdot k_1 \pm s_2 \cdot k_2$ , where  $s_1$ ,  $s_2$  are data of the digital data streams generated using the sigma-delta modulation, and  $k_1$ ,  $k_2$  are assigned correctional factors. In this context, the address sequence generated by accumulation of the values  $d$  of the string of results influences the correctional values in such ~~a way~~ that a linear association with the angular information of the input-side analog signals is produced.

If, in the data of the data streams generated by the sigma-delta modulation, data having a word width of one bit are involved, then the multiplication  $s_1 \cdot k_1$  and  $s_2 \cdot k_2$  yields the values  $k_1$  at  $s_1 = 1$ , and  $-k_1$  at  $s_1 = 0$ , and  $k_2$  at  $s_2 = 1$  and  $-k_2$  at  $s_2 = 0$ . At sufficient word width of the correctional values  $k_1$ ,  $k_2$ , the complement may occur in a simplified manner by the complement on one.

Since, in the case of a word width of one bit, for the data of the digital data streams as the result of the above-explained combination for generating the values  $d$  of the string of results, exactly four cases may be distinguished, the ~~said~~ combination (arithmetic operation)  $s_1 \cdot k_1 \pm s_2 \cdot k_2$  may be combined. The four cases may be represented arithmetically as the sum  $k_1 + k_2$  of the correctional values, the difference  $k_1 - k_2$  of the correctional values, as well as their negatives. If these differences and sums are stored as

correctional values, the expenditure or effort for the arithmetic operations is reduced even more.

A digital interpolation device for carrying out the method  
5 ~~according to the present invention is characterized by the~~  
~~features of Claim 20~~ is also described herein.

~~Other features and advantages of the present invention are~~  
~~clarified in the following description of exemplary~~  
10 ~~embodiments~~ According to an example embodiment of the present  
~~invention, in the light of the figures. The figures show: a~~  
method for interpolating at least two position-dependent,  
periodic analog signals that are phase-shifted with respect to  
one another and which are generated by scanning a measuring  
15 scale includes: converting each of the analog signals into a  
digital data stream by a sigma-delta modulator; generating a  
string of results by combining the data streams with  
correctional factors and subsequently combining the data  
streams with one another; generating from the string of  
20 results (a) new correctional values in accordance with a  
quality criterion that is to be satisfied during interpolation  
and (b) output signals of the interpolation; accumulating over  
a specifiable time interval values of the string of results  
for generating the correctional values and the output signals;  
25 and using a signal sequence generated by the accumulation as  
an address sequence for generating the correctional values and  
for generating the output signal.

According to an example embodiment of the present invention, a  
30 device for interpolating at least two position-dependent,  
periodic analog signals that are phase-shifted with respect to  
each other and which are generated by scanning a measuring  
scale includes: a sigma-delta modulator configured to convert  
the analog signals to a respective digital data stream; an



arithmetic unit configured to generate a string of results in accordance with a combination of the data streams with correctional factors and in accordance with subsequent combination of the data streams with one another; an arrangement configured to generate, from the string of results, (a) new correctional values in accordance with a quality criterion that is to be satisfied during the interpolation and (b) output signals of the interpolation; a filter configured to accumulate values of the string of results over a specified time interval to generate an address sequence to control the arithmetic unit to guide the string of results to satisfy the quality criterion; and an evaluation circuit post-connected to the filter configured to convert address values of the address sequence into output values of the interpolation.

Other features and aspects of the present invention are set forth in the following description of exemplary embodiments with reference to the appended Figure.

#### BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is a schematic ~~representation~~ view of an interpolation device and the appertaining interpolation method for application in the case of position encoders to the measuring of paths and/or angles, by ~~way~~ of a block diagram.

#### DETAILED DESCRIPTION

The starting point of the block diagram shown in Figure 1 is at least two analog signals a1 and a2 that are similar to sines, phase-shifted by  $90^\circ$  with respect to one another, periodic, position-dependent, and obtained by scanning in a position encoder 1 of a measuring system, which are to be used for measuring paths and/or angles. They are in each case converted using sigma-delta modulation in a sigma-delta modulator 3 into digital data streams s1, s2 (word sequences)

of high frequency and low word width, in which amplitude information is contained in the distribution over time of the data. The two data streams s1, s2 having m bit-wide data are accordingly created from analog signals a1 and a2 in each case  
5 by superimposition of a noise signal. This noise signal results from the quantization noise of the sigma-delta modulation.

The data of the digital data streams s1, s2 are multiplied in  
10 a multiplication unit 6 of an arithmetic unit 5 respectively by correctional values k1, k2 from an assignment unit 4, in which a specifiable number of possible correctional values is stored. From the two new strings m1, m2, formed by multiplication of the data by the correctional values k1, k2,  
15 a single string of results d is formed by addition or subtraction of the words of those strings m1, m2 in an addition/subtraction unit 7 of arithmetic unit 5.

After the combination with a quality criterion k3, the values  
20 of string of results d are supplied from assignment unit 4 in combination unit 8 to a filter in the form of an integrating unit 9, in which it is accumulated for the formation of an address sequence a over a specifiable time period. A part ~~(namely~~ (e.g., the higher-value part) of the value accumulated  
25 in integration unit 9 is ~~in-turn~~ combined with a value from assignment unit 4, and the combination result is used directly for addressing for the selection of new correctional values k1, k2 from assignment unit 4 for multiplication by data of the sigma-delta modulation. Alternatively, combination unit 8  
30 may also be positioned behind filter 9, the addressing of the correctional values in assignment unit 4 then taking place of a part of the output value of post-connected unit 8.

In case the quality criterion is not equal to zero, that is,  
35 the input-side analog signals are not sinusoidal or cosinusoidal, quality criterion k3 is ascertained in an

appropriate manner, as was described above in the light of correctional values  $k_1$ ,  $k_2$ .

In the adjusted state, the addresses of the address sequence oscillate between discrete values which represent the best approach to the exact phase setpoint value of the input signals. Output signal  $w$  of the interpolation is formed by closing additional filtering and assignment in an evaluation circuit 10, which includes a digital low-pass filter 11 and an assignment unit 12.

The output of output signal  $w$  takes place as a function of the assignment unit in the form of two square-wave signals that are phase-shifted with respect to each other by  $90^\circ$ , or it takes place in any other desired form (binary, Gray code, ~~...~~ etc.).

Similar to the case of network interpolators, the phase information is obtained during the conversion, and it ~~consists~~ of includes a linear association between the change of the angular value of input-side analog signal  $a_1$  or  $a_2$  and the change of output value  $w$ .

A digital interpolation device is used for the implementation of the above-described method.

Input signals of the interpolation device form two analog signals  $a_1$  and  $a_2$ , that are similar to sines and are phase-shifted with respect to each other by  $90^\circ$ , for instance, coming from incremental position encoders that ~~are known per se~~ may be conventional. In the interpolation device according to an example embodiment of the present invention, from the two analog signals  $a_1$  and  $a_2$ , the output value  $w$  is obtained having the resolution resulting from the demanded degree of interpolation.

First, the two analog signals a1 and a2 are each supplied to a sigma-delta modulator 3. The output signals of sigma-delta modulators 3, two digital data streams s1, s2 having data of low width (e.g., words of 1-bit width) are multiplied in multiplication unit 6 of arithmetic unit 5 by one correctional value k1, k2, respectively, of assignment unit 4, and, after addition or subtraction of the sequences to/from each other in addition/subtraction unit 7 of arithmetic unit 5, the values of string of results d are supplied to integrator 9, whose output signal is an address sequence a composed of address values.

One part of address sequence a is additionally combined with a value from assignment unit 4. The result of the combination determines the selection of correctional values from assignment unit 4 in such a way that a quality criterion k3 is achieved.

The address values of address sequence a represent the phase information sought, acted upon by low residual noise. Subsequent filtering of the address values and the assignment forms interpolated output w.

The possible correctional values k1, k2, which are selected as a function of the current address value, may be stored in assignment unit 4, for example, in the form of a table. If, for instance, in the case of possible correctional values k1, k2, values each of a trigonometric function are involved, this means that, for a certain number of points (e.g., for 16 points), from the value range of the corresponding trigonometric function (e.g., a sine or a cosine function), the respective appertaining functional value is stored from the value range of the trigonometric function as a possible correctional value in the table mentioned above.

Here is a concrete example of this: If the possible values of the one correctional value  $k_1$  are determined to be functional values of a cosine function, then, accordingly, for 16 points out of the definition range ( $0^\circ$  ~~[[ - ]]~~ to  $360^\circ$ ) of the cosine function of the respective appertaining functional value (e.g., the functional value  $\cos 0^\circ = 1$  for the value  $0^\circ$  of the definition range, the functional value  $\cos 22.5^\circ$  for the value  $22.5^\circ$  of the definition range, the functional value  $\cos 45^\circ$  for the value  $45^\circ$  of the definition range, etc.) is stored as the possible value of correctional value  $k_1$  in the table provided for it. From these 16 functional values stored in the table, the respective correctional value  $k_1$  is then selected. The other correctional value  $k_2$  may be represented in corresponding fashion, such as by functional values of a sine function.

The width of the correctional values ~~should~~ may be selected in such ~~a way~~ that at least the number of different functional values ~~can~~ may be represented, i.e., for 16 different functional values from which a correctional value is selected, its width is at least 4 bits. For 32 different functional values, the width of the correctional value would be at least 5 bits, etc. The width of correctional values  $k_1$ ,  $k_2$ , in turn, determines (especially if the word width of the data of the two digital data streams  $s_1$ ,  $s_2$ , that are to be combined with them, amounts to only 1 bit) the width of the values of string of results  $d$ , and thus also the address values of address sequence  $a$ .

Arithmetic unit 5 may, for example, be implemented as follows:

- Arithmetic unit 5 includes two multiplication devices 6, in such ~~a way~~ that, by multiplication, two strings  $m_1 = s_1 * k_1$  and  $m_2 = s_2 * k_2$  are formed from digital data streams  $s_1$ ,  $s_2$  and correctional values  $k_1$ ,  $k_2$  of assignment unit 4, the multiplication by correctional

values k1, k2 being made in each case for the individual data of data streams s1, s2. Subsequently, in addition/subtraction unit 7 the difference m1 - m2 of the two product strings m1, m2 is continuously formed.

5

- At a bit width m = 1 of the individual data of digital data streams s1, s2, the multiplication in multiplication device 6 consists in leaving the value of assignment unit 4 uninfluenced if s1 = '1' or s2 = '1', and in negating if s1 = '0' or s2 = '0'.

10

- At bit width m = 1 of the individual data of digital data streams s1, s2, there are yielded at the two outputs of sigma-delta modulators 3, taken as words, only four different states which, including the addition and subtraction, determine the sums and differences of the values of assignment unit 4 and their negation. When these values are stored in assignment unit 4, this may simplify the addition and subtraction unit and assignment unit 4.

15

20

Integrator 9 is an accumulator in the simplest case. Combination unit 8 is not needed when there is an exactly sinusoidal pattern to input-side analog signals a1, a2 and a phase position of the analog signals of 90° to each other, since the quality criterion becomes k3 = 0 (phase offset). In the case of other signal curves, the values of string d should be combined with quality criterion k3 from assignment unit 4 (addition/subtraction). Integrator 9 directly addresses assignment unit 4 (e.g., ROM) and after final filtering 11 and assignment 12 represents the output signal of interpolating device 2.

25

30

35

In the following, the effect of interpolating device 2 ~~will be~~ is described in greater detail. Interpolating device 2 evaluates the two sine-like analog signals a1 and a2 (sine or

cosine signal) supplied by position encoder 1 and phase-shifted by  $90^\circ$  with respect to each other, in such a way that output signal w of interpolating device 2 represents the path change detected by position encoder 1. Analog signals a1 and a2 supplied by position encoder 1 are changed in the appertaining sigma-delta modulators 3 into two m-bit-wide word strings s1, s2 (digital data streams) of high frequency and low word width of the data. The amplitude information of analog signals a1 and a2 are included in the distribution over time of the data of the two digital data streams s1, s2, at the output of these sigma-delta modulators. Multiplication unit 6, that is subsequent to each of the two data streams s1, s2, forms the new strings m1 and m2 from modulator strings s1, s2 and correctional values k1 and k2 from assignment unit 4. From these strings m1, m2 string of results d is generated in addition and subtraction unit 7, and combined with a quality criterion obtained from assignment unit 4 is supplied to integrator 9.

If there is an exactly sinusoidal curve of input signals a1 and a2, the integrator restores the information  $\beta = \alpha$  according to  $\sin(\alpha) * \cos(\beta) - \cos(\alpha) * \sin(\beta) = \sin(\alpha - \beta)$ , where  $\sin(\alpha)$  and  $\cos(\alpha)$  represent input-side analog signals a1, a2, and  $\cos(\alpha)$  or  $\sin(\beta)$  represent the correctional values k1 and k2 of assignment unit 4, and  $\sin(\alpha - \beta)$  is proportional to the phase increment per scanning.

Other conversion functions may be selected for other kinds of input signals, for example, for correcting errors of the position encoder. In the case of sinusoidal input signals a1, a2,  $\sin(\alpha - \beta)$  is minimized so as to achieve the quality criterion. In other words, the quality criterion is satisfied for  $\alpha = \beta$ . If  $\beta$  is the counter value (address value of assignment unit 4), then, if  $\sin(\alpha - \beta) = 0$ ,  $\beta$  becomes equal to  $\alpha$  and  $\beta$  thus corresponds to the phase position of the input signals.

To summarize, ~~the object of~~ creating a digital interpolation for increasing the resolution of ~~preferably, e.g.,~~ incremental measurement of lengths and/or angles ~~is, may be~~ realized in that, for one, the ~~advantages of the~~ sigma-delta modulation ~~are may be~~ utilized in converting analog input signals into digital data streams. The method of the sigma-delta A/D conversion ~~was may be~~ chosen because the proportion of analog circuit components ~~is may be~~ reduced and a high resolution ~~is may be~~ achievable in the digital part. By utilizing the low-bit output signals of the sigma-delta modulators as input information for an arithmetic unit, arithmetical operations such as multiplication ~~are may be~~ greatly simplified. The formation of only one criterion to be evaluated further ~~simplifies may simplify~~ the digital evaluation circuit (digital filter) and thereby also the circuit integration.

The properties of the method make it possible to integrate the non-linear A/D conversion largely into the digital part of the circuit, so that the interpolating device ~~can may~~ be developed as an integrated circuit. The errors created by other methods, on account of non-ideally analogous component parts, ~~are may be~~ largely avoided.

Going into details, an interpolating method and an interpolating device are ~~proposed provided~~, for signal subdivision (interpolation) of two analog signals (optionally voltage or current) that are sinusoidal and phase-shifted by  $90^\circ$  with respect to each other, ~~especially e.g.,~~ from incremental position encoders for measurement of lengths and/or angles, in which the analog signals are in each case converted using sigma-delta modulation into a data stream of low bit width, in which each item of data from the data stream thus created is multiplied by values from an assignment unit in the case of which the product values of one sequence is added to or subtracted from the product values of the other



sequence, and the string of results thus generated is accumulated, and a part of the accumulation value controls an address unit ~~in such a way~~ that this address unit, on the one hand, addresses the assignment unit and, on the other hand, the output signals are formed via an assignment unit.

An ~~important advantage~~ aspect of the method described above and the appertaining interpolating device is that method steps using correction and having "sigma-delta A/D conversion" are combined, and, in this context, one may do without a costly network, and also, the conversion of the input data into position values is carried out in one step, using the digital conversion with the aid of the sigma-delta modulation. By combination of the principle of correction to the simple sigma-delta A/D conversion, the analog part of the interpolating device ~~is~~ may be reduced to a minimum and its digital part ~~is~~ may be simplified. It is possible to construct the entire interpolating device as an integrated circuit, using easily available technologies.

Abstract

ABSTRACT

~~The present invention relates to~~ In a method for  
interpolating, for the purpose of measurement of lengths  
and/or angles, at least two position-dependent, periodic  
5 analog signals that are phase-shifted with respect to each  
other and that are generated by scanning a measuring scale.  
~~According to the inventive method,~~ the analog signals are  
converted to a digital data stream using a sigma-delta  
10 modulator, the data streams are combined with correctional  
factors and then with each other to generate a string of  
results, and ~~said~~ the string of results is used to generate  
new correctional values by the use of a quality criterion to  
be satisfied for interpolation and also to generate the output  
15 signals of interpolation. The values ~~(d)~~ of the string of  
results are accumulated over a specified time interval in  
order to generate the correctional values ~~(k1, k2)~~ and the  
output signals ~~(w)~~. The signal sequence generated by  
accumulation is used directly as the address sequence for  
20 generating the correctional values ~~(k1, k2)~~ and the output  
signal ~~(b)~~.